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Oscillator strengths and lifetimes in P V, S VI and Cl VII

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Abstract Energy levels as well as oscillator strengths and transition probabilities for transitions among the terms belonging to configurations within the principal quantum number $n = 6$ of Na-like phosphorous, sulphur, and chlorine are computed using configuration-interaction wave functions The calculations have been carried out in both *LS* and intermediate-coupling schemes The relativistic effects in intermediate coupling are incorporated by means of the Breit-Pauli Hamiltonian We have also calculated the lifetimes from our radiative decay rates Our calculated energy levels, oscillator strengths and lifetimes are compared with other theoretical results and experimental data

Keywords Atomic energy levels, oscillator strengths, transition probabilities

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1. Introduction

The determination of accurate oscillator strengths, transition probabilities for atoms and ions aims to provide reliable atomic data useful in many important applications. Elements in the Na isoelectronic sequence are of considerable interest in the study of high energy plasmas because the adjacent Na-like ions are being used in research to develop X-ray lasers [1]. A Na-like recombination scheme is most likely to achieve lasing action in the water window (23.3–48.8 Å). Accurate transition probabilities are needed for determination of the gain coefficients for this type of laser.

The study of the various atomic parameters such as oscillator strengths and lifetimes of the third row elements and their ions has many important astrophysical applications [2-4]. In particular, atomic transitions from these elements are expected to be prominent in the absorption spectra of interstellar gas clouds [5] and they have been observed as absorption features superposed on the spectra of several stars [6]. Sulphur is one of the more abundant elements in the universe and its spectra yield many astrophysically interesting quantities [7,8]. Several spectral lines due to sulphur ions have been observed in the ultraviolet (UV) and extreme ultraviolet (EUV) spectra of the Io plasma torus in the magnetosphere of Jupiter [9-13]. Some new spectral lines due to these ions have also been observed by the Goddard High Resolution Spectrograph on board the Hubble Space Telescope [14], and the high-resolution Hopkins Ultraviolet Telescope on board ASTRO-1 [15]. The emission lines at wavelengths near 1400 Å in the solar spectrum have been recorded by NRL normal-incidence slit spectrograph (S082-B) on Skylab [16]. Joelsson *et al* [17] have observed the spectra from sliding spark and beam-foil sources over the 152-5577 Å region and classified some 90 lines as S VI transitions.

Previously, several workers have reported their results for energy levels, oscillator strengths and transition probabilities for the ions of Na-isoelectronic sequence [18–23]. The oscillator strengths for few electric-dipole allowed transitions and the lifetimes for low lying states in P V, S VI and Cl VII, have been calculated using the *LS* coupling scheme [2,24–26]. The experimental results for oscillator strengths and the lifetimes are also available [27–33]. Froese Fischer [26] studied the *Z*-dependent correlation effects and calculated the *f*-values in the sodium

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iso-electronic sequence using a frozen core, multi-configuration Hartree-Fock procedure. Zhang *et al* [23] calculated the energy levels and radiative transition probabilities for Na-like ions with $38 \leq Z \leq 45$ using the multi-configuration Dirac-Fock approach. Sampson *et al* [21] calculated the oscillator strengths and collision strengths for 71 Na-like ions with $22 \leq Z \leq 92$ using Dirac-Fock-Slater and relativistic-distorted-wave approach, respectively. Kundu *et al* [34] calculated the frequency-dependent dipole polarizability of the sodium iso-electronic sequence ($Z = 11$–18) within linear-response theory using the time-dependent coupled Hartree-Fock scheme

Here, we present our calculated excitation energies for the lowest 16 *LS* and 29 fine-structure levels as well as oscillator strengths and transition probabilities for the transitions among the $(1s^22s^22p^6)$ $3s(^2S)$, $3p(^2P^0)$, $3d(^2D)$, $4s(^2S)$, $4p(^2P^0)$, $4d(^2D)$, $4f(^2F^0)$, $5s(^2S)$, $5p(^2P^0)$, $5d(^2D)$, $5f(^2F^0)$, $5g(^2G)$, $6s(^2S)$, $6p(^2P^0)$, $6d(^2D)$, $6f(^2F^0)$, $6g(^2G)$ states in Na-like phosphorous, sulphur, and chlorine. The calculations have been carried out in both *LS* and intermediate-coupling schemes. The relativistic effects in intermediate coupling are incorporated by means of the Breit-Pauli Hamiltonian [35].

2. Method of calculation

We considered 17 LS terms belonging to the configurations within the principal quantum number $n = 6$ of P V, S VI, and Cl VII. These terms are represented by configuration-interaction (Cl) wave functions given by [36,37]

$$\psi(LS\,\pi) = \sum_{i}^{M} a_i \phi_i(\alpha_i\, LS\,\pi), \tag{1}$$

where each of the ϕ_i is constructed from orbitals whose angular momenta are coupled, as specified by α_i, to form a total L and S common to all M configurations in eq. (1). The radial part of each orbital is a sum of normalized Slater-type orbitals

$$P_{nl} = \sum_{i=1} C_i \left[(2\xi_i)^{2p_i+1}/(2p_i)!\right]^{1/2} r^{p_i} \exp(-\xi_i r) \tag{2}$$

where n and l, respectively, are the principal and orbital quantum numbers and C_i, ξ_i and p_i are the expansion coefficients, exponents, and powers of r, respectively.

In this calculation, we have chosen the $1s$, $2s$, $2p$ functions as those given by Clementi and Roetti [38] for the ground state $(1s^22s^22p^6)$ $3s(^2S)$ of the ions considered here. The $3s$, $3p$, $3d$, $4s$, $4p$, $4d$, $4f$, $5s$, $5p$, $5d$, $5f$, $5g$, $6s$, $6p$, $6d$, $6f$, $6g$ functions are chosen as spectroscopic type and are optimized on the energies of the $3s(^2S)$, $3p(^2P^0)$, $3d(^2D)$, $4s$ (^2S), $4p(^2P^0)$, $4d(^2D)$, $4f(^2F^0)$, $5s(^2S)$, $5p(^2P^0)$, $5d(^2D)$, $5f(^2F^0)$, $5g(^2G)$, $6s(^2S)$, $6p(^2P^0)$, $6d(^2D)$, $6f(^2F^0)$, and $6g(^2G)$ states, respectively. In all cases we chose $k = n - l$ so that the coefficients C_i are uniquely specified by the orthogonality condition on P_{nl} [36]. The CI wave functions given by eq (1) are then used to calculate the excitation energies, oscillator strengths and radiative transition probabilities in *LS* coupling scheme

The J-dependent CI wave functions are constructed by using expansions of the form [35]

$$\Psi_i(JM_J) = \sum_{j=1}^{K} b_{ij} \phi_j(\alpha_j L_j S_j JM_J),$$

where each of the K single-configuration functions ϕ_j is constructed from one-electron functions and α_j defines the coupling of the orbital L_j and the spin S_j angular momenta to give the total angular momentum J. The mixing coefficients b_{ij} are obtained by diagonalizing the Breit-Pauli Hamiltonian with respect to the basis ϕ_j [35]. The Hamiltonian is represented by the non-relativistic electrostatic interactions plus the Breit-Pauli terms such as one-body mass correction, Darwin term, and spin-orbit, spin-other-orbit, and spin-spin operators. The inclusion of mass correction, Darwin and spin-spin terms shift the energy of a configuration as a whole while the spin-orbit and spin-other-orbit terms cause the fine-structure splitting. The radial parts of the one-electron functions expressed in analytic forms as a sum of Slater-type orbitals, are given by eq. (2). The wave functions given by eq. (3) are used to calculate the excitation energies of the fine-structure levels, length and velocity forms of the oscillator strengths, and transition probabilities among the fine-structure levels.

The radiative lifetime of an excited state is calculated from the radiative transition probabilities using the relation

$$\tau_j = 1/\Sigma_i A_{ji}, \tag{4}$$

where the sum over i is over all accessible final states.

3. Results and discussion

In Table 1, is presented our *ab initio* calculations of excitation energies of the 16 low-lying levels relative to the ground state for P V, S VI and Cl VII. For P V and Cl VII, our calculated results are compared with the experimental values of Moore [39] and for S VI, they are compared with the experimental data of Joelsson *et al* [17], compiled by Martin *et al* [40]. As seen, nearly all of our calculated values agree better than 1.0% with the experimental results for the three ions studies here.

In Table 2, we have listed our radiative decay rates in the length approximation (A_L) and the absorption oscillator

Table 1. Calculated and experimental energy levels relative to the ground state (in a u)

Index	Term	P V		S VI		Cl VII	
		Present	Experiment MR	Present	Experiment JN	Present	Experiment MR
1	$3s^2S$	0 0	0 0	0 0	0 0	0 0	0 0
2	$3p^2P^0$	0 4054	0 4063	0 4849	0 4862	0 5635	0 5662
3	$3d^2D$	0.9289	0 9304	1 1276	1 1274	1 3226	1 3223
4	$4s^2S$	1 2295	1 2437	1 6375	1 6539	2 0949	2 1142
5	$4p^2P^0$	1 3725	1 3867	1 8128	1 8293	2 3022	2 3222
6	$4d^2D$	1 5602	1 5738	2 0428	2 0586	2.5742	2 5933
7	$4f^2F^0$	1 5867	1 6065	2 0848	2 1080	2 6339	2 6613
8	$5s^2S$	1 6981	1 7161	2 2758	2 2969	2 9261	2 9510
9	$5p^2P^0$	1 7646	1 7824	2 3583	2 3792	3 0247	
10	$5d^2D$	1 8537	1 8710	2 4679	2 4880	3 1544	3 1785
11	$5f^2F^0$	1 8680	1 8884	2 4900	2 5140	3 1856	3 2041
12	$5g^2G$	1 8685	1 8894	2 4909	2 5156	3 1870	
13	$6s^2S$	1.9269	1 9463	2 5913	2 6141	3 3409	
14	$6p^2P^0$	1 9631	1 9825	2 6365	2 6592	3 3952	
15	$6d^2D$	2 0127	2 0313	2 6973	2 7195	3 4674	
16	$6f^2F^0$	2 0209	2 0415	2 7103	2 7347	3 4855	3 5154
17	$6g^2G$	2 0213	2 0422	2 7109	2 7357	3 4864	

MR Experimental results of Moore [39]

JN Experimental results of Joelsson *et al* [17]

Table 2. Transition probabilities and oscillator strengths for allowed transitions

Transition	P V			S VI			Cl VII		
	A_l	f_l	f_v	A_l	f_l	f_v	A_l	f_l	f_v
$3s(^2S)$ $3p(^2P^0)$	1 316(9)	0 748	0 709	1 734(9)	0 689	0 656	2 167(9)	0.637	0 608
$-$ $4p(^2P^0)$	1 039(9)	0 051	0 053	2.620(9)	0 074	0 076	5 398(9)	0 095	0 095
$-$ $5p(^2P^0)$	7.040(8)	0 021	0 021	1 691(9)	0 028	0 028	3 432(9)	0 035	0 035
$-$ $6p(^2P^0)$	4 319(8)	0 010	0 011	1 051(9)	0 014	0 014	2 116(9)	0 017	0 017
$4s(^2S)$ $-$ $4p(^2P^0)$	2 399(8)	1 095	1.076	3 318(8)	1 007	0 976	4 289(8)	0 932	0.918
$-$ $5p(^2P^0)$	1 301(8)	0 042	0 044	3 651(8)	0 066	0 068	8 253(8)	0 089	0.091
$-$ $6p(^2P^0)$	1 083(8)	0 019	0.021	2 803(8)	0 026	0 029	6 084(8)	0 034	0.036
$5s(^2S)$ $-$ $5p(^2P^0)$	6.718(7)	1 420	1 427	9 539(7)	1 310	1 302	1 261(8)	1 212	1 196
$-$ $6p(^2P^0)$	3.247(7)	0 043	0 038	8 893(7)	0 064	0 065	2 083(8)	0 088	0 090
$6s(^2S)$ $-$ $6p(^2P^0)$	2 434(7)	1 741	1.733	3 513(7)	1.607	1.590	4 690(7)	1.484	1 480
$3p(^2P^0)$ $-$ $4s(^2S)$	7.119(9)	0.109	0.103	1 291(10)	0 101	0 095	2.119(10)	0 094	0.088
$-$ $5s(^2S)$	2.934(9)	0 018	0 016	5 433(9)	0 018	0 016	9.241(9)	0 017	0 015
$-$ $6s(^2S)$	1 429(9)	0.007	0 006	2 965(9)	0.007	0.006	5 139(9)	0 007	0.006
$-$ $3d(^2D)$	4 036(9)	0.764	0.898	5.405(9)	0 679	0.817	6 718(9)	0.605	0.742
$-$ $4d(^2D)$	6 714(8)	0 026	0 018	2.810(9)	0 060	0.047	7 474(9)	0 096	0.081
$-$ $5d(^2D)$	8 091(8)	0.020	0 015	2.641(9)	0.035	0 027	6.236(9)	0 048	0 039
$-$ $6d(^2D)$	5 939(8)	0 012	0 009	1.962(9)	0 021	0 015	4.468(9)	0.027	0 020

Table 2. *(Cont'd)*

Transition	P V			S VI			Cl VII		
	A_L	f_L	f_V	A_l	f_l	f_V	A_l	f_L	f_l
$4p(^2P^0) - 5s(^2S)$	1 936(9)	0 189	0 188	3 592(9)	0 174	0 170	6 008(9)	0 160	0 159
$- 6s(^2S)$	8 491(8)	0 029	0 029	1 667(9)	0 029	0 028	2.757(9)	0 027	0 027
$- 4d(^2D)$	7 515(8)	1 107	1 158	1 012(9)	0 993	1 049	1 277(9)	0 895	0 932
$- 5d(^2D)$	2 683(7)	0 006	0 005	2 384(8)	0 029	0 025	7 971(8)	0 057	0 054
$- 6d(^2D)$	4 086(7)	0 005	0 007	2 767(8)	0.018	0 018	6 832(8)	0.026	0 029
$5p(^2P^0) - 6s(^2S)$	6 829(8)	0 269	0 271	1 291(9)	0 246	0 247	2 200(9)	0 228	0 229
$- 5d(^2D)$	2 173(8)	1 421	1 447	2 988(8)	1 289	1 301	3 778(8)	1 166	1 176
$- 6d(^2D)$	5 120(5)	0 001	0 001	2 931(7)	0 013	0.014	1 377(8)	0 036	0 038
$6p(^2P^0) - 6d(^2D)$	8 174(7)	1 723	1 735	1 119(8)	1 566	1.579	1 428(8)	1 422	1 434
$3d(^2D) - 4p(^2P^0)$	1.274(9)	0 121	0 154	2 554(9)	0 101	0 133	4 437(9)	0 086	0 114
$- 5p(^2P^0)$	4 027(8)	0 011	0 017	8 397(8)	0 010	0 016	1 484(9)	0 010	0 015
$- 6p(^2P^0)$	1 964(8)	0.003	0 005	3 782(8)	0 003	0 005	6 598(8)	0 003	0 005
$- 4f(^2F^0)$	9 147(9)	0 921	0 927	1 915(10)	0 911	0 916	3 574(10)	0 906	0 909
$- 5f(^2F^0)$	3 350(9)	0 166	0 169	7 165(9)	0 168	0 170	1 347(10)	0 169	0 171
$- 6f(^2F^0)$	1 670(9)	0 061	0 062	3 525(9)	0 061	0 063	6 656(9)	0 062	0 063
$4d(^2D) - 5p(^2P^0)$	5 771(8)	0 258	0 268	1.184(9)	0 222	0 225	2 100(9)	0 193	0 191
$- 6p(^2P^0)$	2 450(8)	0 028	0 029	5 254(8)	0 028	0 027	9 786(8)	0 027	0 025
$- 4f(^2F^0)$	1 786(6)	0 111	0 127	4 968(6)	0 123	0 141	1 054(7)	0 129	0 149
$- 5f(^2F^0)$	1 569(9)	0 721	0 707	3.259(9)	0 710	0 692	6 027(9)	0 703	0 685
$- 6f(^2F^0)$	9 262(8)	0 190	0 174	1 927(9)	0 188	0 171	3 579(9)	0 188	0 171
$5d(^2D) - 6p(^2P^0)$	2 527(8)	0.394	0 397	5 168(8)	0 340	0.339	9 232(8)	0 297	0 292
$- 5f(^2F^0)$	1 007(6)	0 213	0 225	2 559(6)	0 228	0.253	5 273(6)	0 236	0 261
$- 6f(^2F^0)$	4 003(8)	0 623	0 622	7 387(8)	0 622	0 596	1 543(9)	0 613	0 590
$6d(^2D) - 6f(^2F^0)$	4 683(5)	0.298	0 308	1 249(6)	0.323	0 335	2 493(6)	0 332	0 343
$4f(^2F^0) - 5d(^2D)$	6 378(7)	0.020	0 021	1.392(8)	0 021	0 022	2 626(8)	0 022	0 023
$- 6d(^2D)$	2 695(7)	0 003	0 004	5 867(7)	0 003	0 003	1 093(8)	0 003	0 004
$- 5g(^2G)$	2.665(9)	1.343	1.343	5.530(9)	1.342	1 342	1 025(10)	1.341	1 341
$- 6g(^2G)$	8 638(8)	0.183	0 183	1 794(9)	0 183	0 183	3 330(9)	0 183	0 183
$5f(^2F^0) - 6d(^2D)$	4.666(7)	0.050	0.050	1 012(8)	0.052	0.053	1 903(8)	0 053	0.054
$- 5g(^2G)$	1.938(1)	0.004	0.004	9 064(1)	0 005	0 005	2 928(2)	0 006	0 006
$- 6g(^2G)$	6 916(8)	1 178	1.178	1.434(9)	1 176	1.176	2 658(9)	1.175	1.173
$6f(^2F^0) - 6g(^2G)$	2 123(1)	0.008	0.007	9.152(1)	0 010	0.013	2.935(2)	0 012	0 013
$5g(^2G) - 6f(^2F^0)$	7 363(6)	0.008	0.008	1.543(7)	0.008	0.008	2.881(7)	0 008	0 008

strengths, in both length f_L and velocity f_V formulations, for all dipole-allowed transitions among the 17 *LS* states of P V, S VI and Cl VII. For all strong and even some weaker transitions, there is very good agreement between our length and velocity values of the oscillator strengths for all cases.

Interestingly, the absorption oscillator strengths for the dipole-allowed transitions involving the same higher principal quantum number have larger oscillator strength values compared to those with lower n values and P V has the greater oscillator strength value followed by S VI and then by Cl VII for the same value of n. This can be expressed compactly as the oscillator strengths for the transition $nl - n(l+1) >$ for $(n-1)\,l - (n-1)\,(l+1) >$ for $(n-2)\,l - (n-2)(l+1) >$ for $(n-3)\,l - (n-3)(l+1)$, where $n = 6$ and $l = 0$ or 1. Those transitions involving $4f$ or $5f$ or $6f$ have f-values much smaller than unity, except for the transitions such as $nd - (n+1)f$, $3 \le n \le 5$ and $nf - (n+1)g$, $4 \le n \le 5$ whose f-values are significant, greater than 0.7. Some of the transitions, depending on their wavelengths and f-values could have interesting implications for ion lasers.

In Table 2(a), our calculated f_L values for a few strong dipole-allowed transitions are compared with other calculated

Table 2(a). Comparison of present absorption oscillator strength with other theoretical and experimental results.

Ion	Transition	Present	Experiment	Other calculations
P V	$3s(^2S)$– $3p(^2P^0)$	0.748	0 60 ± 0.03[a]	0 67[g]
			0 80 ± 0.16[b]	0.75[h]
				0.70[i]
	$3p(^2P^0)$– $3d(^2D)$	0.764	0 59 ± 0 04[a]	0 69[g]
			0.63 ± 0.13[b]	
	$4f(^2F^0)$– $5g(^2G)$	1.343	0.89 ± 0.11[a]	
S VI	$3s(^2S)$– $3p(^2P^0)$	0 689	0 56 ± 0 03[c]	0.64[g]
			0 37 ± 0 02[d]	0 69[h]
			0 53[c]	0 65[i]
	$3p(^2P^0)$– $3d(^2D)$	0 679	0.51 ± 0.08[c]	0.62[g]
			0 13 ± 0.02[d]	
	$3d(^2D)$– $4f(^2F^0)$	0 911	0 45 ± 0 09[c]	0 92[j]
Cl VII	$3s(^2S)$– $3p(^2P^0)$	0.637	0.53[f]	0 64[h]
				0.60[i]

a Experiment of Livingston *et al* [30], b Experiment of Curtis *et al* [28]; c Experiment of Irwin and Livingston [29], d Experiment of Berry *et al* [33], e Experiment of Sorenson [31], f Experiment of Bashkin and Martinson [32], g Calculation of Crossley and Dalgarno [24]; h Calculation of Biemont [25], i Calculation of Froese Fischer [26], j Calculation of Wiese *et al* [2].

values [2,24–26] and the available experimental results [28–33]. Our results are in excellent agreement with the calculated values of Biemont [25] and Wiese *et al* [2] and are in reasonable accord with those of the other calculations. For P V, our calculated values agree with the experimental results of Curtis *et al* [28] and for S VI they are closer to the experimental values of Irwin and Livington [29]. The two experimental results [28,30] show considerable discrepancies for the transitions in P V.

In Table 3, we have tabulated our calculated lifetimes for P V, S VI and Cl VII. We have also reported other theoretical results [2,24,25] and the experimental data [27–30] to compare with our calculations. Our results are in good agreement with the other calculations for P V and S VI. For P V, our calculated values are in reasonable agreement, within the experimental errors, with the measured results of Curtis *et al* [28]. However, the experimental results of Livingston *et al* [30] overestimate our calculations and the experimental values of Curtis *et al* [28]. For S VI the two experiments [27,29] agree very well on the lifetimes of the two levels $3p(^2P^0)$ and $3d(^2D)$ but only reasonably well with our calculated values. Our lifetimes for the $4f(^2F^0)$ and

Table 3. Comparison of present lifetimes (in nanoseconds) with other theoretical and experimental results

Upper State	P V Present	P V Other results	S VI Present	S VI Other results	Cl VII Present
$3p^2P^0$	0 7597	0 95 ± 0 05[a] 0 70 ± 0.15[b] 0 84[c]	0.5766	0.69 ± 0.04[c] 0 67 0 03[d]	0 4614
$3d^2D$	0 2477	0 32 ± 0 02[a] 0 30 ± 0 06[b] 0.27[c]	0.1850	0 25 ± 0 04[c] 0 25 ± 0 01[d]	0.1489
$4s^2S$	0 1405		0 0775		0 0470
$4p^2P^0$	0 3917		0 1816		0 0974
$4d^2D$	0.7028		0 2616		0 1143
$4f^2F^0$	0.1093		0.0522	0.10 ± 0.02[c] 0 05[f]	0 0280
$5s^2S$	0.2053		0 1108		0.0656
$5p^2P^0$	0.5316		0.2395		0.1255
$5d^2D$	0.8952		0 3015		0 1303
$5f^2F^0$	0.2033		0.0959	0.13 ± 0.02[d] 0.095[g]	0.0513
$5g^2G$	0.3752	0.56 ± 0 07[a]	0.1808	0.24 ± 0.04[d]	0.0975
$6s^2S$	0 3307		0 1689		0.0990
$6p^2P^0$	0.7745		0 3478		0.1805
$6d^2D$	1.2648		0.3937		0.1745
$6f^2F^0$	0.3329		0.1585		0.0847
$6g^2G$	0.6429		0.3098	0.21 ± 0.04[d]	0.1670

a : Experiment of Livingston *et al* [30], b . Experiment of Curtis *et al* [28]; c : Experiment of Irwin and Livingston [29]; d : Experiment of Dumont *et al* [27]; e : Calculation of Crossley and Dalgarno [24]; f : Calculation of Wiese *et al* [2]; g : Calculation of Biemont [25].

$5f(^2F^0)$ levels agree excellently with those of the other calculations [2,25], but only well with the measured values [27,29] when the experimental errors are considered. For the transitions involving the g orbital, we do not expect good agreement with the measurements because of our neglect of the contributions from higher states. Hence, the fair accord with the measurement of Dumont *et al* [27] on the lifetimes of the $5g(^2G)$ and $6g(^2G)$ levels.

It is interesting to note that for the three ions studied here, the lifetimes of the states with the same orbital quantum number (l) increases with the increase of the principal quantum number (n) except for the state with $l = 1$ where for $n = 3$ the lifetime is large compared to that of the states with higher value of n. This may be due to the fact that the $3p(^2P^0)$ state decays through the transition to the ground state only. Also the lifetime decreases from P V to Cl VII for the same state.

In Table 4, our calculated fine-structure energies relative to ground states for P V and Cl VII are compared with the experimental results of Moore [39], whereas for

Table 4. Fine-structure energy levels relative to the ground state (in a u)

Index	Term	J	P V		S VI		Cl VII	
			Present	Experiment MR	Present	Experiment JN	Present	Experiment MR
1	$3s^2S$	0 5	0.0	0 0	0.0	0 0	0.0	0 0
2	$3p^2P^0$	0 5	0 4080	0 4039	0 4884	0 4824	0 5682	0.5604
3		1 5	0 4109	0 4075	0 4932	0 4882	0 5755	0 5690
4	$3d^2D$	1 5	0 9352	0 9304	1.1372	1 1273	1 3365	1 3221
5		2 5	0 9353	0 9304	1 1375	1 1275	1 3369	1 3224
6	$4s^2S$	0 5	1 2337	1 2437	1 6440	1 6539	2 1043	2 1142
7	$4p^2P^0$	0 5	1 3776	1.3859	1 8204	1 8279	2.3131	2 3201
8		1.5	1.3786	1.3872	1.8221	1 8299	2 3158	2.3232
9	$5d^2D$	1 5	1 5666	1 5738	2 0526	2 0585	2 5884	2 5932
10		2 5	1.5666	1 5738	2.0527	2 0586	2 5886	2.5934
11	$5f^2F^0$	2 5	1 5931	1 6065	2 0947	2 1080	2 6484	2 6613
12		3.5	1 5931		2 0948		2 6485	2 6614
13	$5s^2S$	0.5	1 7036	1 7161	2.2842	2 2968	2 9383	2 9510
14	$5p^2P^0$	0.5	1 7704	1.7820	2 3671	2.3785	3.0375	
15		1 5	1.7709	1.7826	2 3679	2 3795	3 0388	
16	$5d^2D$	1 5	1 8601	1 8710	2 4778	2 4880	3 1788	3.1785
17		2.5	1 8601		2 4778	2 4880	3.1689	3 1786
18	$5f^2F^0$	2.5	1 8745	1.8884	2.5000	2.5140	3.2002	3.2140
19		3.5	1 8745		2 5000		3 2002	3.2141
20	$5g^2G$	3.5	1.8750	1 8894	2.5009	2.5156	3.2016	
21		4 5	1 8750		2.5009		3.2016	
22	$6s^2S$	0 5	1 9329	1 9463	2.6004	2 6141	3 3542	
23	$6p^2P^0$	0 5	1 9692	1 9825	2 6458	2 6589	3 4089	
24		1 5	1.9694		2 6463	2 6594	3 4096	
25	$6d^2D$	1.5	2 0191	2.0313	2.7073	2.7195	3.4819	
26		2 5	2 0191		2.7073	2 7195	3.4820	
27	$6f^2F^0$	2.5	2.0274	2.0415	2.7203	2.7347	3.5001	3.5154
28		3 5	2.0274		2.7203		3 5001	
29	$6g^2G$	3.5	2 0277	2.0422	2.7209	2.7357	3.5011	
30		4.5	2.0278		2 7209		3 5011	

MR · Experimental results of Moore [39]

JN · Experimental results of Joelsson *et al* [17]

S VI they are compared with the experimental values of Joelsson *et al* [17], compiled by Martin *et al* [40]. As seen, our results including their ordering agree to better than 1.0% with the experimental data for all three ions.

Tabulated in Table 5, are our calculated oscillator strengths in both the length f_l and velocity f_v forms and transition probabilities in the length form A_l among all 30 fine-structure levels in P V, S VI and Cl VII. The keys of the

Table 5. Oscillator strengths and transition probabilities among all fine-structure levels

	P V			S VI			Cl VII		
Tran	f_l	f_v	A_l	f_l	f_v	A_l	f_l	f_v	A_l
1 - 2	2.50(-1)	2.36(-1)	1.33(9)	2.30(-1)	2.18(-1)	1.76(9)	2.13(-1)	2.02(-1)	2.21(9)
1 - 3	5.03(-1)	4.70(-1)	1.36(9)	4.65(-1)	4.33(-1)	1.82(9)	4.32(-1)	4.01(-1)	2.30(9)
1 - 7	1.68(-2)	1.75(-2)	1.02(9)	2.43(-2)	2.51(-2)	2.59(9)	3.11(-2)	3.16(-2)	5.34(9)
1 - 8	3.27(-2)	3.45(-2)	9.98(8)	4.73(-2)	4.96(-2)	2.52(9)	6.04(-2)	6.24(-2)	5.20(9)
1 - 14	6.72(-3)	7.13(-3)	6.77(8)	9.05(-3)	9.39(-3)	1.63(9)	1.12(-2)	1.15(-2)	3.31(9)
1 - 15	1.32(-2)	1.42(-2)	6.65(8)	1.78(-2)	1.87(-2)	1.60(9)	2.19(-2)	2.30(-2)	3.25(9)
1 - 23	3.03(-3)	3.55(-3)	3.77(8)	4.09(-3)	4.61(-3)	9.21(8)	4.97(-3)	5.49(-3)	1.85(9)
1 - 24	5.99(-3)	7.14(-3)	3.73(8)	8.10(-3)	9.28(-3)	9.12(8)	9.84(-3)	1.11(-2)	1.84(9)
2 - 4	7.67(-1)	8.94(-1)	3.42(9)	6.83(-1)	8.13(-1)	4.62(9)	6.10(-1)	7.37(-1)	5.78(9)
2 - 6	1.08(-1)	1.02(-1)	2.38(9)	1.00(-1)	9.43(-2)	4.31(9)	9.34(-2)	8.79(-2)	7.08(9)
2 - 9	2.49(-2)	1.76(-2)	5.38(8)	5.79(-2)	4.66(-2)	2.27(9)	9.27(-2)	7.98(-2)	6.08(9)
2 - 13	1.80(-2)	1.61(-2)	9.69(8)	1.73(-2)	1.54(-2)	1.79(9)	1.68(-2)	1.48(-2)	3.03(9)
2 - 16	1.92(-2)	1.45(-2)	6.51(8)	3.36(-2)	2.71(-2)	2.14(9)	4.66(-2)	3.91(-2)	5.06(9)
2 - 22	6.45(-3)	5.80(-3)	4.82(8)	6.63(-3)	5.58(-3)	9.50(8)	6.54(-3)	5.43(-3)	1.63(9)
2 - 25	1.08(-2)	8.61(-3)	4.50(8)	1.91(-2)	1.46(-2)	1.51(9)	2.54(-2)	1.99(-2)	3.46(9)
3 - 4	7.65(-2)	8.97(-2)	6.75(8)	6.79(-2)	8.16(-2)	9.05(8)	6.06(-2)	7.41(-2)	1.13(9)
3 - 5	6.88(-1)	8.07(-1)	4.05(9)	6.12(-1)	7.34(-1)	5.44(9)	5.45(-1)	6.67(-1)	6.77(9)
3 - 6	1.10(-1)	1.03(-1)	4.77(9)	1.02(-1)	9.45(-2)	8.67(9)	9.50(-2)	8.82(-2)	1.43(10)
3 - 9	2.59(-3)	1.79(-3)	1.11(8)	5.96(-3)	4.72(-3)	4.66(8)	9.53(-3)	8.08(-3)	1.24(9)
3 - 10	2.32(-2)	1.61(-2)	6.65(8)	5.36(-2)	4.25(-2)	2.79(9)	8.56(-2)	7.26(-2)	7.43(9)
3 - 13	1.82(-2)	1.60(-2)	1.95(9)	1.76(-2)	1.53(-2)	3.62(9)	1.72(-2)	1.47(-2)	6.16(9)
3 - 16	1.98(-3)	1.46(-3)	1.34(8)	3.45(-3)	2.72(-3)	4.37(8)	4.78(-3)	3.92(-3)	1.03(9)
3 - 17	1.78(-2)	1.32(-2)	8.02(8)	3.11(-2)	2.45(-2)	2.62(9)	4.30(-2)	3.53(-2)	6.19(9)
3 - 22	6.59(-3)	5.75(-3)	9.81(8)	6.82(-3)	5.53(-3)	1.95(9)	6.78(-3)	5.37(-3)	3.36(9)
3 - 25	1.16(-3)	8.62(-4)	9.65(7)	2.03(-3)	1.47(-3)	3.20(8)	2.68(-3)	1.99(-3)	7.29(8)
3 - 26	1.04(-2)	7.76(-3)	5.79(8)	1.83(-2)	1.32(-2)	1.92(9)	2.42(-2)	1.79(-2)	4.37(9)
4 - 7	1.01(-1)	1.28(-1)	1.27(9)	8.54(-2)	1.11(-1)	2.56(9)	7.28(-2)	9.46(-2)	4.46(9)
4 - 8	2.02(-2)	2.56(-2)	1.27(8)	1.69(-2)	2.22(-2)	2.55(8)	1.44(-2)	1.90(-2)	4.44(8)
4 - 11	9.21(-1)	9.27(-1)	8.54(9)	9.10(-1)	9.16(-1)	1.8(10)	9.05(-1)	9.09(-1)	3.34(10)
4 - 14	8.94(-3)	1.39(-2)	4.01(8)	8.62(-3)	1.35(-2)	8.38(8)	7.98(-3)	1.28(-2)	1.48(9)
4 - 15	1.79(-3)	2.81(-3)	4.02(7)	1.72(-3)	2.74(-3)	8.38(7)	1.59(-3)	2.59(-3)	1.48(8)
4 - 18	1.65(-1)	1.69(-1)	3.13(9)	1.68(-1)	1.70(-1)	6.69(9)	1.69(-1)	1.71(-1)	1.26(10)
4 - 23	2.82(-3)	4.70(-3)	1.94(8)	2.56(-3)	4.72(-3)	3.74(8)	2.36(-3)	4.49(-3)	6.53(8)
4 - 24	5.69(-4)	9.59(-4)	1.96(7)	5.14(-4)	9.64(-4)	3.76(7)	4.74(-4)	9.19(-4)	6.54(7)
4 - 27	6.09(-2)	6.23(-2)	1.56(9)	6.12(-2)	6.30(-2)	3.29(9)	6.18(-2)	6.359(-2)	6.20(9)
5 - 8	1.21(-1)	1.54(-1)	1.15(9)	1.02(-1)	1.33(-1)	2.30(9)	8.66(-2)	1.14(-1)	4.00(9)
5 - 11	4.38(-2)	4.41(-2)	6.10(8)	4.34(-2)	4.36(-2)	1.28(9)	4.31(-2)	4.33(-2)	2.38(9)

Table 5. *(Cont'd.).*

	P V			S VI			Cl VII		
Tran.	f_L	f_V	A_L	f_L	f_V	A_L	f_L	f_V	A_L
5 – 12	8.77(–1)	8 83(–1)	9 15(9)	8.67(–1)	8 72(–1)	1.9(10)	8.62(–1)	8 66(–1)	3.57(10)
5 – 15	1.07(–2)	1 69(–2)	3 62(8)	1 03(–2)	1.64(–2)	7.54(8)	9.55(–3)	1.55(–2)	1.33(9)
5 – 18	7.88(–3)	80.3(–3)	2.23(8)	8.00(–3)	8 10(–3)	4 77(8)	8 04(–3)	8.13(–3)	8.97(8)
5 – 19	1.58(–1)	1.61(–1)	3 35(9)	1 60(–1)	1 62(–1)	7.19(9)	1 61(–1)	1.63(–1)	1.35(10)
5 – 24	3.42(–3)	5.75(–3)	1 76(8)	3.09(–3)	5 78(–3)	3.39(8)	2 85(–3)	5.51(–3)	5.91(8)
5 – 27	2 90(–3)	2.97(–3)	1 11(8)	2 91(–3)	3.00(–3)	2.35(8)	2 94(–3)	3.02(–3)	4 43(8)
5 – 28	5.81(–2)	5 94(–2)	1 67(9)	5 83(–2)	6 00(–2)	3 52(9)	5.89(–2)	6 05(–2)	6 65(9)
6 – 7	3.66(–1)	3.58(–1)	2.43(8)	3 37(–1)	3 25(–1)	3.37(8)	3.12(–1)	3 05(–1)	4.37(8)
6 – 8	7.37(–1)	7.16(–1)	2.48(8)	6.80(–1)	6.49(–1)	3.47(8)	6 31(–1)	6.10(–1)	4.54(8)
6 – 14	1 37(–2)	1 47(–2)	1 26(8)	2 12(–2)	2 24(–2)	3 57(8)	2 89(–2)	3 03(–2)	8.08(8)
6 – 15	2.64(–2)	2.88(–2)	1.23(8)	4.11(–2)	4 41(–2)	3.46(8)	5 58(–2)	5.95(–2)	7 83(8)
6 – 23	5.70(–3)	6.87(–3)	9.91(7)	7.98(–3)	9 50(–3)	2 57(8)	1 02(–2)	1.18(–2)	5.59(8)
6 – 24	1.12(–2)	1.37(–2)	9 71(7)	1 56(–2)	1 89(–2)	2.52(8)	2 00(–2)	2.35(–2)	5 49(8)
7 – 9	1.11	1.16	6.38(8)	9 99(–1)	1 05	8.66(8)	9.03(–1)	9 31(–1)	1.10(9)
7 – 13	1.89(–1)	1.88(–1)	6.46(8)	1.73(–1)	1 70(–1)	1.20(9)	1 59(–1)	1 59(–1)	2.00(9)
7 – 16	5.33(–3)	4 59(–3)	1.99(7)	2.69(–2)	2.38(–2)	1 87(8)	5.38(–2)	5 24(–2)	6.33(8)
7 – 22	2.82(–2)	2 92(–2)	2.79(8)	2.79(–2)	2.75(–2)	5 46(8)	2.58(–2)	2.69(–2)	8.99(8)
7 – 25	4.38(–3)	7.40(–3)	2 89(7)	1.66(–2)	1.74(–2)	2 10(8)	2.38(–2)	2.93(–2)	5 22(8)
8 – 9	1.11(–1)	1 16(–1)	1 26(8)	9.94(–2)	1.05(–1)	1 70(8)	8 96(–2)	9.32(–2)	2 14(8)
8 – 10	9 97(–1)	1.04	7.55(8)	8 95(–1)	9 43(–1)	1.02(9)	8 07(–1)	8.39(–1)	1 29(9)
8 – 13	1.91(–1)	1.89(–1)	1.29(9)	1 76(–1)	1 71(–1)	2.41(9)	1 62(–1)	1.60(–1)	4 04(9)
8 – 16	5.86(–4)	4.83(–4)	4.37(6)	2 84(–3)	2.45(–3)	3.93(7)	5 63(–3)	5.37(–3)	1 32(8)
8 – 17	5.25(–3)	4.34(–3)	2.16(7)	2.55(–2)	2 20(–2)	2 35(8)	5.05(–2)	4 82(–2)	7 87(8)
8 – 22	2.85(–2)	2.91(–2)	5.62(8)	2.83(–2)	2.74(–2)	1 10(9)	2 63(–2)	2.68(–2)	1.82(9)
8 – 25	4.96(–4)	7.51(–4)	6.54(6)	1.79(–3)	1.76(–3)	4 50(7)	2 56(–3)	2.96(–3)	1.11(8)
8 – 26	4.45(–3)	6 75(–3)	3.91(7)	1.61(–2)	1.59(–2)	2.69(8)	2 29(–2)	2 66(–2)	6 66(8)
9 – 11	1.12(–1)	1.27(–1)	1.68(6)	1 23(–1)	1.42(–1)	4.69(6)	1.29(–1)	1.49(–1)	9.99(6)
9 – 14	2.16(–1)	2.23(–1)	5.77(8)	1.87(–1)	1.88(–1)	1.19(9)	1.63(–1)	1.62(–1)	2.11(9)
9 – 15	4.30(–2)	4.46(–2)	5.77(7)	3.71(–2)	3.75(–2)	1.18(8)	3.22(–2)	3.23(–2)	2 10(8)
9 – 18	7.21(–1)	7.07(–1)	1.46(9)	7 09(–1)	6.91(–1)	3.04(9)	7 01(–1)	6.84(–1)	5.62(9)
9 – 23	2.33(–2)	2.36(–2)	2.43(8)	2.31(–2)	2.23(–2)	5.22(8)	2 25(–2)	2 06(–2)	9.27(8)
9 – 24	4.69(–3)	4.78(–3)	2.44(7)	4.63(–3)	4.52(–3)	5.24(7)	4.50(–3)	4.19(–3)	9.75(7)
9 – 27	1.90(–1)	1 74(–1)	8.64(8)	1.88(–1)	1.71(–1)	1.80(9)	1 87(–1)	1 71(–1)	3 33(9)
10 – 11	5.30(–3)	6.06(–3)	1.19(5)	5 86(–3)	6.73(–3)	3.32(5)	6.14(–3)	7.10(–3)	7.06(5)
10 – 12	1.06(–1)	[illegible]	1.79(6)	1.17(–1)	1.35(–1)	5.00(6)	1.23(–1)	1.42(–1)	1.06(7)
10 – 15	2.58(–1)	[illegible]	5.19(8)	2.23(–1)	2.25(–1)	1.07(9)	1.94(–1)	1 94(–1)	1.89(9)
10 – 18	3.43(–2)	[illegible]	1.05(8)	3.38(–2)	3.29(–2)	2.17(8)	3.34(–2)	3.26(–2)	4.02(8)
10 – 19	6.87(–1)	[illegible]	1.57(9)	6.76(–1)	6.59(–1)	3.26(9)	6.68(–1)	6.52(–1)	6.02(9)
10 – 24	2.81(–2)	[illegible]	2.20(8)	2.78(–2)	2.71(–2)	4.72(8)	2.70(–2)	2.51(–2)	8.78(8)
10 – 27	9.04(–3)	[illegible]	6.17(7)	8.96(–3)	8.16(–3)	1.28(8)	8.93(–3)	8.14(–3)	2.38(8)
10 – 28	1.81(–1)	1.65(–1)	9.26(8)	1.79(–1)	1.63(–1)	1.93(9)	1.79(–1)	1.63(–1)	3.58(9)

Table 5. *(Cont'd.)*.

	P V			S VI			Cl VII		
Tran	f_L	f_V	A_L	f_L	f_V	A_L	f_L	f_V	A_L
11 - 16	1.86(-2)	1.96(-2)	6.38(7)	1.97(-2)	2.12(-2)	1.39(8)	2.02(-2)	2 18(-2)	2.63(8)
11 - 17	1.33(-3)	1.40(-3)	3.04(6)	1.40(-3)	1.51(-3)	6.63(6)	1 44(-3)	1 56(-3)	1.25(7)
11 - 20	1.34	1.34	2.57(9)	1.34	1.34	5.33(9)	1.34	1.34	9.88(9)
11 - 25	3.07(-3)	3.37(-3)	2.69(7)	3.24(-3)	3.60(-3)	5.85(7)	3.25(-3)	3.69(-3)	1 09(8)
11 - 26	2.19(-4)	2 40(-4)	1.28(6)	2.31(-4)	2.57(-4)	2 78(6)	2 32(-4)	2 63(-4)	5.18(6)
11 - 29	1.83(-1)	1.83(-1)	8 33(8)	1.83(-1)	1 83(-1)	1.73(9)	1 83(-1)	1.83(-1)	3.21(9)
12 - 17	1.99(-2)	2 10(-2)	6 08(7)	2 11(-2)	2 27(-2)	1.33(8)	2 16(-2)	2.34(-2)	2 50(8)
12 - 20	3 73(-2)	3 73(-2)	9.52(7)	3 73(-2)	3.73(-2)	1 97(8)	3.72(-2)	3 72(-2)	3.66(8)
12 - 21	1.31	1.31	2 66(9)	1.30	1.30	5.53(9)	1.30	1.30	1.02(10)
12 - 26	3.30(-3)	3 61(-3)	2.56(7)	3.47(-3)	3 86(-3)	5.58(7)	3.49(-3)	3 95(-3)	1 04(8)
12 - 29	5.08(-3)	5.09(-3)	3.08(7)	5.08(-3)	5 09(-3)	6.41(7)	5.09(-3)	5.09(-3)	1.19(8)
12 - 30	1.78(-1)	1.78(-1)	8.64(8)	1.78(-1)	1.78(-1)	1.79(9)	1.78(-1)	1.78(-1)	3.33(9)
13 - 14	4 75(-1)	4 74(-1)	6 81(7)	4.38(-1)	4.32(-1)	9 68(7)	4 06(-1)	3 98(-1)	1.28(8)
13 - 15	9.56(-1)	9.48(-1)	6.95(7)	8.85(-1)	8.66(-1)	9.97(7)	8.21(-1)	7.96(-1)	1.33(8)
13 - 23	1 35(-2)	1.28(-2)	3.06(7)	2 01(-2)	2.16(-2)	8 43(7)	2.79(-2)	2.99(-2)	1.98(8)
13 - 24	2 61(-2)	2.51(-2)	2 96(7)	3 87(-2)	4 24(-2)	8.16(7)	5.38(-2)	5.87(-2)	1 92(8)
14 - 16	1 43	1 44	1.84(8)	1 30	1.30	2.55(8)	1 18	1.18	3.26(8)
14 - 22	2 68(-1)	2 70(-1)	2 27(8)	2.45(-1)	2 46(-1)	4.29(8)	2.27(-1)	2.27(-1)	7.31(8)
14 - 25	1.83(-4)	5 64(-4)	1 82(5)	1 13(-2)	1.39(-2)	2.10(7)	3.27(-2)	3.68(-2)	1.04(8)
15 - 16	1 42(-1)	1 45(-1)	3 64(7)	1 29(-1)	1.30(-1)	1.01(7)	1.17(-1)	1 17(-1)	6.34(7)
15 - 17	1.28	1 30	2 18(8)	1.16	1.17	3 01(8)	1.05	1.06	3.81(8)
15 - 22	2.71(-1)	2 71(-1)	4 56(8)	2 48(-1)	2.47(-1)	8.63(8)	2.30(-1)	2.29(-1)	1.47(9)
15 - 25	3 62(-5)	6 41(-5)	7 16(4)	1 27(-3)	1 44(-3)	4 27(6)	3.55(-3)	3.79(-3)	2.24(7)
15 - 26	3 19(-4)	5 71(-4)	4 21(5)	1.14(-2)	1.29(-2)	2.81(7)	3.18(-2)	3.40(-2)	1.34(8)
16 - 18	2 14(-1)	2 26(-1)	9 48(5)	2 29(-1)	2.54(-1)	2.42(6)	2 37(-1)	2.61(-1)	5.00(6)
16 - 23	3 30(-1)	3 30(-1)	2 52(8)	2 85(-1)	2.82(-1)	5.16(8)	2.49(-1)	2.43(-1)	9.24(8)
16 - 24	6 58(-2)	6.61(-2)	2.53(7)	5 66(-2)	5.64(-2)	5.17(7)	4.96(-2)	4.87(-2)	9.23(7)
16 - 27	6.22(-1)	6 21(-1)	3.73(8)	6 21(-1)	5.95(-1)	7.82(8)	6.11(-1)	5.89(-1)	1.44(9)
17 - 18	1.02(-2)	1.07(-2)	6.73(4)	1.09(-2)	1.21(-2)	1.71(5)	1.13(-2)	1.24(-2)	3.53(5)
17 - 19	2 03(-1)	2.14(-1)	1 01(6)	2.17(-1)	2.41(-1)	2.58(6)	2.26(-1)	2.48(-1)	5.32(6)
17 - 24	3.94(-1)	3.97(-1)	2 27(8)	3 40(-1)	3.39(-1)	4.65(8)	2.98(-1)	2.92(-1)	8.31(8)
17 - 27	2 97(-2)	2.96(-2)	2.67(7)	2 96(-2)	2.84(-2)	5.59(7)	2.92(-2)	2.81(-2)	1.03(8)
17 - 28	5.93(-1)	5.92(-1)	4 00(8)	5.92(-1)	5.67(-1)	8.38(8)	5.83(-1)	5 62(-1)	1.54(9)
18 - 20	3 68(-3)	4 09(-3)	2.01(1)	4.84(-3)	5.57(-3)	9.46(1)	9.85(-3)	6.69(-3)	3.09(2)
18 - 25	4.63(-2)	4.69(-2)	4 67(7)	4.89(-2)	4.94(-2)	1.01(8)	4.98(-2)	5.02(-2)	1.90(8)
18 - 26	3.30(-3)	3.35(-3)	2 22(6)	3.49(-3)	3.53(-3)	4.82(6)	3.55(-3)	3.58(-3)	9.06(6)
18 - 29	1.18	1.18	6.67(8)	1.17	1.17	1.38(9)	1.17	1.17	2.56(9)
19 - 20	9.98(-5)	1.12(-4)	6.9(-1)	1.31(-4)	1.52(-4)	3.25	1.58(-4)	1.82(-4)	1.05(1)
19 - 21	3.54(-3)	3.91(-3)	2 03(1)	4.66(-3)	5.31(-3)	9.53(1)	5.62(-3)	6.37(-3)	3.10(2)
19 - 26	4.96(-2)	5.02(-2)	4.44(7)	5.24(-2)	5.29(-2)	9.64(7)	5.33(-2)	5.37(-2)	1.81(8)
19 - 29	3.27(-2)	3.27(-2)	2.47(7)	3.27(-2)	3.26(-2)	5.12(7)	3.26(-2)	3.26(-2)	9.49(7)

Table 5. *(Cont'd).*

	P V			S VI			Cl VII		
Tran.	f_l	f_v	A_L	f_L	f_v	A_L	f_L	f_v	A_L
19 - 30	1.15	1.15	6.92(8)	1.14	1.14	1.43(9)	1.14	1.14	2.66(9)
20 - 27	7.39(-3)	7 43(-3)	7 36(6)	7.47(-3)	7.54(-3)	1 54(7)	7.54(-3)	7.62(-3)	2.88(7)
20 - 28	2 73(-4)	2.75(-4)	2 04(5)	2 77(-4)	2.79(-4)	4.28(5)	2.79(-4)	2.82(-4)	7.98(5)
21 - 28	7.67(-3)	7.70(-3)	7.16(6)	7 76(-3)	7 82(-3)	1.50(7)	7.82(-3)	7.89(-3)	2 80(7)
22 - 23	5 84(-1)	5.72(-1)	2 47(7)	5 40(-1)	5.24(-1)	3 58(7)	4.99(-1)	4.88(-1)	4 79(7)
22 - 24	1.17	1.14	2.52(7)	1.09	1 05	3 68(7)	1.01	9.75(-1)	4.97(7)
23 - 25	1 74	1.72	6 96(7)	1 58	1 57	9 59(7)	1.44	1 42	1 23(8)
24 - 25	1 73(-1)	1.73(-1)	1.37(7)	1.57(-1)	1.58(-1)	1.87(7)	1 43(-1)	1 43(-1)	2 40(7)
24 - 26	1.55	1.56	8 22(7)	1.41	1.42	1 13(8)	1.28	1 29	1.44(8)
25 - 27	2 99(-1)	3.08(-1)	4 41(5)	3 25(-1)	3 36(-1)	1 18(6)	3 34(-1)	3.44(-1)	2 36(6)
26 - 27	1.42(-2)	1.47(-2)	3 13(4)	1.54(-2)	1 60(-2)	8.36(4)	1.59(-2)	1 64(-2)	1.67(5)
26 - 28	2.84(-1)	2.94(-1)	4 71(5)	3.09(-1)	3 20(-1)	1 26(6)	3 18(-1)	3.27(-1)	2 52(6)
27 - 29	8.21(-3)	7 93(-3)	2 18(1)	1 05(-2)	1 35(-2)	9 44(1)	1 27(-2)	1.45(-2)	3 06(2)
28 - 29	2.24(-4)	2.17(-4)	7.6(-1)	2.86(-4)	3.71(-4)	3.28	3 43(-4)	3.97(-4)	1 05(1)
28 - 30	7.93(-3)	7.52(-3)	2.21(1)	1 01(-2)	1.28(-2)	9.55(1)	1 22(-2)	1 37(-2)	3 08(2)

lower and upper levels involved in a transition are given in Table 4 for these ions. For all strong and even for some relatively weaker transitions, there is good agreement between the length (f_l) and velocity (f_v) values of the oscillator strengths indicative to some extent the accuracy of the wave functions used in this calculation. However, for few weaker transitions, there is considerable difference between the two values of oscillator strengths. The small oscillator strengths are sensitive to cancellation effects. In cases where the values of f_L and f_V differ, the length value of our oscillator strength is preferred over the velocity value. It is because the integral for the dipole matrix element involves the operator 'r', which samples the outer region of the wave functions that is generally more accurately calculated than the inner region which is sampled by the velocity operator.

4. Conclusions

Here, we have presented calculated excitation energies from ground state of Na-like phosphorous, sulphur, and chlorine as well as oscillator strengths and transition probabilities for the transitions among the $(1s^22s^22p^6)\,3s(^2S)$, $3p(^2P^0)$, $3d(^2D)$, $4s(^2S)$, $4p(^2P^0)$, $4d(^2D)$, $4f(^2F^0)$, $5s(^2S)$, $5p(^2P^0)$, $5d(^2D)$, $5f(^2F^0)$, $5g(^2G)$, $6s(^2S)$, $6p(^2P^0)$, $6d(^2D)$, $6f(^2F^0)$, and $6g(^2G)$ states. The calculations have been carried out in both *LS* and intermediate-coupling schemes.

Good agreement has been obtained between our calculated and the measured values of both the *LS* and fine-structure energy levels for the three ions P V, S VI and Cl VII. Overall, our *f*-values agree excellently with the calculated values [2,25], but for P V they agree only with the experimental data of Curtis *et al* [28] while for S VI they are closer to those of Irwin and Livingston [29]. However, the two experimental results disagree considerable on the transitions in P V Concerning the lifetimes of P V and S VI, our values agree with those of other calculations but the experimental picture is clouded. For P V our results agree reasonably well with the data of Curtis *et al* [28], but the results of Livingston *et al* [30] overestimate our calculation and the measurement of Curtis *et al* [28]. Interestingly, for S VI the two experiments [27,29] agree very well with each other, but only reasonably well with our calculated values.

In conclusion, additional experimental and theoretical investigations on lifetimes and *f*-values for P V, S VI and Cl VII are clearly still needed for definitive results.

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